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(54) **2-wire telemetry system with power regulator in transmitter**

(57) A DC powered transmitter, eg for fluid flow rate, termperature or pressure, gives a dc signal, in accordance with the sensed variable, supplied over a two-wire line W_1, W_2 to a receiver 13 in which a DC voltage supply is connected to the line through load resistor 12. Across resistor 12 is an output signal in a predetermined current range for operating an indicator. The same line supplies operating power to the power input terminals of the transmitter through a switching-type step down power regulator 17 that gives constant power under high voltage-low current as well as under low voltage-high current conditions, thereby making more power available to the transmitter and increasing its load drive capability.

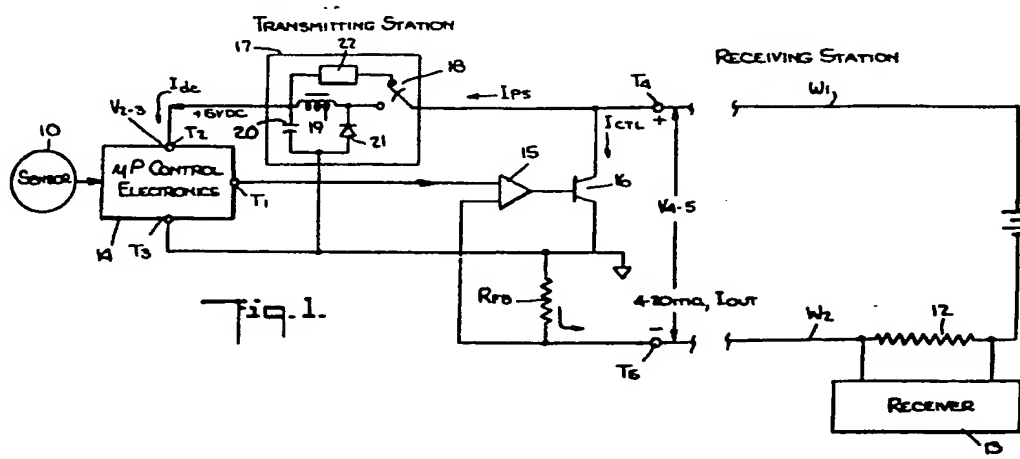

Fig. 1.

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.
This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1982.

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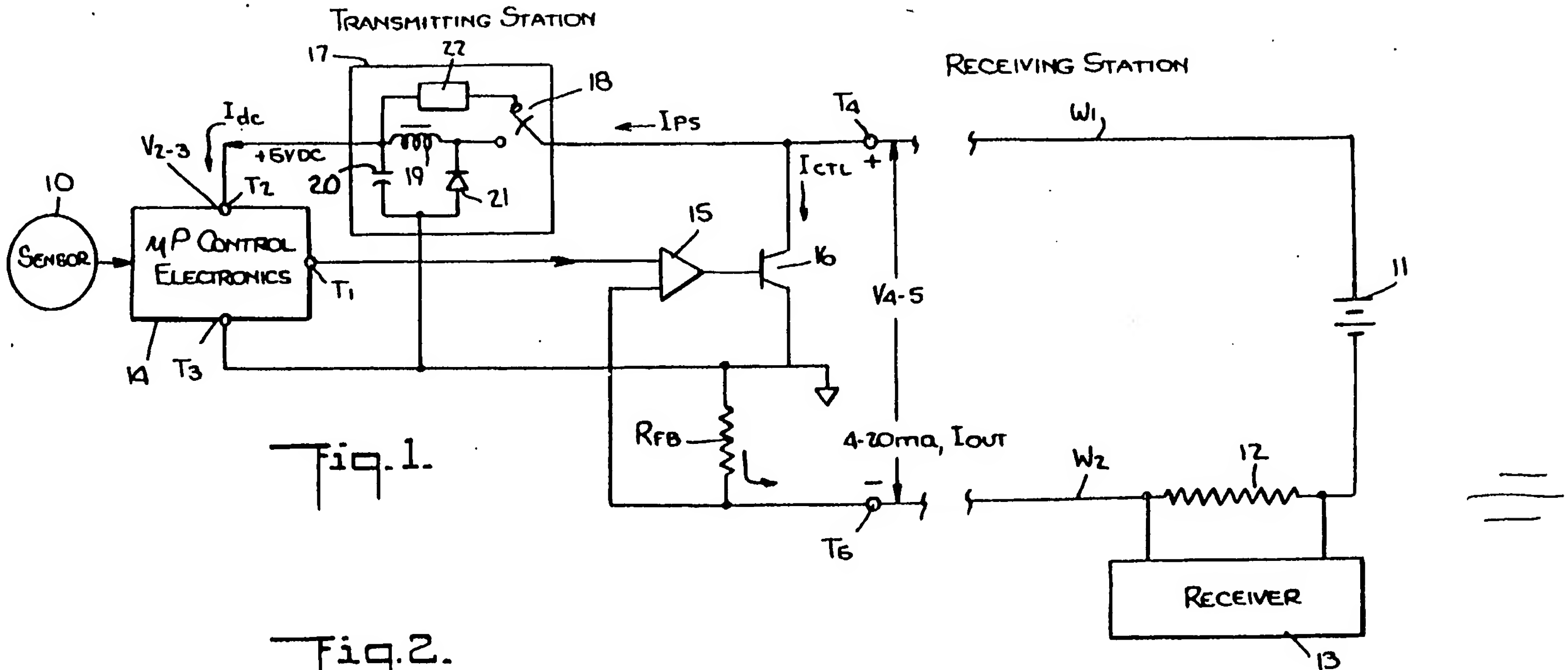


Fig. 1.

Fig. 2.

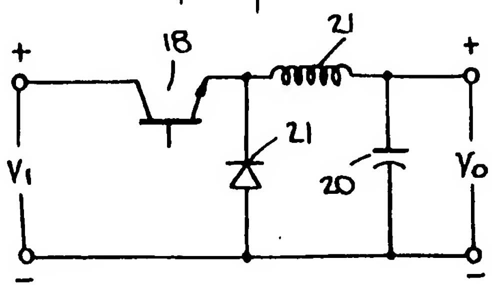
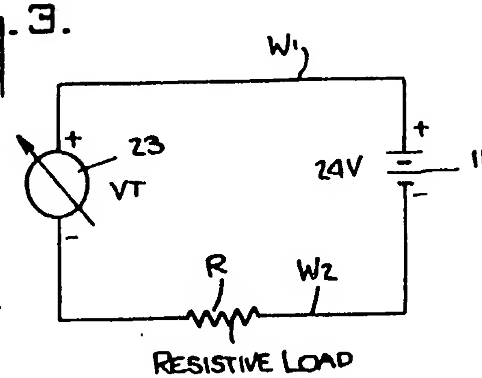


Fig. 3.



TITLE OF THE INVENTION

TWO-WIRE TELEMETERING SYSTEM INCLUDING POWER REGULATED TRANSMITTING DEVICE

BACKGROUND OF INVENTION

Field of Invention:

This invention relates generally to a telemetering system in which a direct-current signal yielded by a transmitting device responsive to a variable of interest is conveyed over a two-wire line to a receiving station having a DC power supply whose output is supplied to the transmitting device over the same line to provide operating power therefor, and more particularly to a system of this type capable of supplying a relatively large amount of power to the transmitting device.

Status of Prior Art:

A two-wire telemetering system is particularly useful in an industrial process control loop in which a value sensed at a transmitting device by a thermocouple or other sensor of the process variable being metered is converted into a direct-current signal that is conveyed over a two-wire line to a remote receiving station for operating indicators, recorders, controllers or other instruments in the process control loop. Systems of this type are disclosed in the Herzl et al. patent 4,084,155, the Shauger patent 4,158,765, and the Sterling et al. patent 4,692,328.

One important advantage of a two-wire telemetering system is that the same wires serve not only to convey the current signal from the transmitting device to the station but also to conduct operating power from the receiving station to the transmitting device, thereby obviating the need for extra wires in remote control applications. Also,

a current output minimizes susceptibility of the system to voltage noise spikes and eliminates line drop problems.

For a process control telemetering system, American National Standard ANSI-MC 12.1 - 1975 and ISA-S 50.1, "Compatibility of Analog Signals for Electronic Industrial process Instruments" specify that the standard output signal (of a transmitting device) shall be a current a range of 4 mA to 20 mADC [Section 3.2 of the Standard], and that the standard voltage signal (of the receiver) shall be 1 volt to 5 volt dc [Section 3.3.2 of the Standard]. These standards are generally accepted and practiced by the industrial process control industry.

It has been found that known telemetering systems of this type fail in some instances to supply adequate operating power for transmitting devices. For example, if the transmitting device is a differential-pressure (D-P) transducer operating in conjunction with a square root extractor, the power demands of the D-P transducer and the associated square root extractor are not satisfied at low input levels when the device operates in the usual 4 to 20 mAdc range. And if one wishes to include a microprocessor in a transmitting device, because of the existing constraints in power availability, this may not be possible.

It is known to effect linear regulation of the power supply voltage for the transmitting device in a two-wire telemetering system. But such linear regulators act to restrict power consumption of the transmitter control circuitry and to reduce its drive capability. Typically, a two-wire

transmitter is specified with a minimum power supply operating voltage with stated conditions, a linear relationship being established between operating voltage and the resistance load drive capability.

For example, operation at 12.5 volts and zero ohms may be specified as well as operation at 24 volts and 500 ohms. The internal transmitter control electronics is necessarily limited to a current consumption of less than 3.8 mA, for the operating range of the system is 4 to 20 mA. Hence the higher the minimum operating voltage, the lower the load resistance must be.

By reason of such power limitations, it may become necessary in many instances to operate the telemetering system in a four-wire configuration rather than with a two-wire line. Thus additional wires are required to convey adequate operating power to the transmitting device, thereby sacrificing the important benefits of a two-wire system.

For any two-wire loop, the transmitter control electronics power consumption is limited by the external power supply voltage (the source of all power consumed in the loop) and the minimum operational current in the loop (4 ma). For example, the power consumption of the control electronics of all standard two-wire transmitters is limited to 4 ma$\cdot$ ^{V} power supply.

If the control electronics inside the transmitter requires a voltage equal to the power supply voltage, then 4 ma is the maximum current which can be consumed. However,

in a situation where the control electronics requires less than the power supply voltage, then a higher current consumption can be achieved. The invention is addressed to this situation by providing more power to the transmitter control electronics when the control electronics is implemented with circuitry requiring relatively low voltage with respect to the available voltage, rather than limiting the power consumption to 4 ma • V low.

SUMMARY OF INVENTION

In view of the foregoing, the main object of this invention is to provide a two-wire telemetering system wherein the same line conducts a direct-current signal from a field station transmitting device to a receiving station which supplies operating power at a substantially constant level to the transmitting device, the amount of operating power supplied being sufficient even at low signal levels to energize relatively complex transmitting devices such as magnetic flowmeters, field-mounted multiplexers and microprocessor-based transmitting transmitting devices.

More particularly, an object of the present invention is to provide a two-wire telemetering system of the above type in which the power supplied to the transmitting device is regulated by a switching-type power regulator that delivers to the power input terminals of the device substantially constant power under high voltage-low current as well as under low voltage-high current conditions.

Also an object of the invention is to provide a two-wire telemetering system of the above type which is of relatively simple, low cost construction, yet operates efficiently and reliably.

Briefly stated, these objects are attained in a telemetering system in which a DC powered transmitting device responsive to a process or other variable yields a direct-current signal in accordance with the variable that is supplied over a two-wire line to a receiving station in which a DC voltage supply is connected to the line through a load resistor. Developed across this resistor is an output signal in a predetermined current range for operating an indicator or other instrument. The same line supplies operating power to the power input terminals of the transmitting device through a switching-type step down power regulator that yields constant power under high voltage-low current as well as under low voltage-high current conditions, thereby making more power available to the transmitting device and increasing its load drive capability.

BRIEF DESCRIPTION OF DRAWINGS

For a better understanding of the invention as well as other objects and further features thereof, reference is made to the following detailed description to be read in conjunction with the accompanying drawings, wherein:

Fig. 1 is a schematic circuit diagram of a two-wire telemetering system in accordance with the invention;

Fig. 2 is a schematic circuit diagram of the basic elements of a step-down switching-type regulator included in the system; and

Fig. 3 is a simplified circuit representing the general case in regard to the amount of power which is available when linear and when switching-type regulation is used in the system.

DETAILED DESCRIPTION OF INVENTION

The Telemetering System:

Referring now to Fig. 1, there is shown in this figure the basic components of a two-wire telemetering system in accordance with the invention which includes a DC-powered transmitting device responsive to a process or other variable whose value is metered by a sensor 10. The transmitting device is linked by a two-wire line W_1 and W_2 to a remote receiving station in which a DC power supply represented by battery 11 is connected in series with a load resistor 12 through which flows an output signal in the standard current range (i.e., 4 to 20 mAdc). The voltage developed across load resistor 12 is applied to a receiver 13 which may be a process variable indicator, a recorder, a controller and any other device appropriate to process control. The two wire line W_1 and W_2 are connected to the transmitter device at terminals T_4 and T_5.

Sensor 10 may be a thermocouple, a differential-pressure transducer or any other field-mounted device for metering the process variable. This variable may be fluid flow rate, temperature or pressure to produce an analog signal proportional thereto. In the example shown, this analog signal is applied to the microprocessor-controlled circuit 14.

The output yielded by microprocessor-controlled circuit 14 which appears at terminal T_1 is applied to one input of a differential amplifier 15 to whose other input is applied a feedback voltage developed across a feedback resistor R_{FB}. The output of amplifier 15 modulates an output transistor 16 connected in series with resistor R_{FB} between lines W_1 and W_2.

Microprocessor-controlled circuit 14 is provided with power input terminals T_2 and T_3, terminal T_3 being connected to line W_2 through resistor R_{FB} at terminal T_5. Terminal T_2 is connected to line W_1 through a switching-type power regulator 17 at terminal T_4. Regulator 17 serves to supply relatively high power to the microprocessor-controlled circuit 14 at a constant level, which remains substantially unchanged under high voltage-low current as well as low voltage-high current conditions.

The voltage between terminals 2 and 3 is V_{2-3}, while that between terminals 4 and 5 is V_{4-5}. The current going into regulator 17 is designated I_{ps}, and the current from regulator 17 into the microprocessor-controlled circuit 14 is designated I_{dc}. Voltage V_{2-3} is determined by the

power supply specifications of the components used in microprocessor-controlled circuit 14. Typically, voltage V_{2-3} is 5Vdc.

The aim of the invention is to obtain an I_{dc} current which is greater than I_{ps} current at the regulated 5Vdc voltage in order to satisfy the current requirements of the microprocessor-controlled circuit 14. This goal is achieved by switching regulator 17 when V_{2-3} is lower than V_{4-5} as will later be explained.

Switching-type power regulators suitable for this purpose are disclosed in the following publications, whose disclosures are incorporated herein by reference:

A. 1987 "Switchmode (A Designers Guide for Switching Power Supply Circuits and Components) published by Motorola Corporation.

B. "Applications Handbook (1987-1988)" published by Unirode Corporation.

C. "Linear and Interface Circuit Applications 1985" (Section C - Switching Power Design) published by Texas Instruments.

Regulator 17 includes a transistor switch 18 which switches on and off at a predetermined frequency. During the interval switch 18 is on, the input voltage is applied to the input of an LC filter formed by an inductor 19 and a capacitor 20, thereby causing the current to increase. When the switch is off, the energy stored in inductor 19 maintains current flow to the load, circulating through a "catch" diode 21.

The regulator is monitored and controlled by a control circuit generally represented by block 22. This control circuit includes an oscillator driving a pulse width modulator, an error amplifier and a precision voltage reference. The error amplifier compares the input reference voltage with a sample of the voltage from the filter circuit. As the load increases, the output voltage drops. The error amplifier senses this drop and causes the pulse-width modulator to remain on for a longer period of time, delivering wider control pulses to transistor switch 18.

The width of the pulse determines how long the transistor switch permits current to flow and therefore how much current is yielded at the output. If the load decreases, narrower control pulses are delivered to the switching transistor until the output voltage remains at a constant value.

<u>The Step-Down Power Regulator</u>:

Switch-type power regulators are available in three basic configurations:

(1) A step-down or "buck" regulator

(2) A step-up or "boost" regulator

(3) an inverting regulator

The present invention makes use of a step-down power regulator whose operation will now be explained in connection with Fig. 2. It will be seen that transistor switch 18 is placed in series with inductor 19 between the DC input V_1 and the DC output V_0, diode 21 being connected to the input side of the inductor and capacitor 20 to the output side thereof.

Transistor switch 18 in the buck circuit interrupts the DC input voltage to supply a variable width pulse to the simple averaging filter formed by inductor 21 and capacitor 20. When switch 18 is closed, the input voltage is applied across this filter and current flows through inductor 21 to the load. When switch 18 is open, the energy stored in the field of the inductor maintains the current through the load.

In this buck circuit, peak switching current is proportional to the load current. The output voltage V_0 is equal to the input voltage V_1 times the duty cycle. Hence the output voltage is always less than the input voltage in the step-down switching regulator.

Comparison of Regulators:

A linear series or shunt regulator, because it functions in a continuous mode, will dissipate relatively large amounts of power. Typically, the efficiency of a linear regulator is less than 50%. And when the input-to-output voltage differential is large, the resultant efficiency then falls to well below 40%. In contradistinction, a switching-type power regulator, which uses the on-off cycle of a transistor switch to regulate power, has typical efficiencies running well over 60%.

There are three reasons why a switching-type regulator achieves much higher efficiencies than a linear regulator. First, since the power transistor switch is turned either off or on, this results in either low current or low voltage during most of its operation. Second, good regulation is attainable over a wide range of input voltages, and third, high efficiency can be achieved over wide ranges in load current.

To further explain these distinctions, reference is now made to Fig. 3 in which element 23 represents the transmitter which is supplied with a voltage V_T by battery 11 (24 volts) through a two-wire line W_1 and W_2 in series with a load resistor R.

The power dissipated (PD) by transmitter 23 is expressed by the following equations:

$$PD = 24\ I - RI^2 = V_T I \text{ (Power Dissipated by Transmitter)}$$

$$@ I = 4ma,\ PD = 96mW - R\ (16\ uW/ohm)$$
$$= 0 \leq R \leq 6K\ ohm$$

$$@ I = 20ma\ PD = 480\ mW - R\ (400\ uW/ohm)$$
$$= 0 \leq R \leq 1.2K\ ohm$$
$$= V_T = 24 - 20\ (10^{-3})\ R$$

For linear regulation the maximum power (PE) available for the electronics in the transmitter is:

$$PE = 4ma \cdot V_T\ @\ 20ma$$
$$= 4ma \cdot [24 - 20\ (10^{-3}) \cdot R\ ]$$
$$= 96\ mW - (80\ uW/ohm) \cdot R$$

For a switching-type regulator, the maximum power (PE) available for the electronics in the transmitter is:

$$PE = \alpha PD_{MIN} = \alpha \left\{ 96 \text{ MW} - R \text{ (16 uW/ohm)} \right\};$$

where α is the efficiency of the switching regulator

$$PE = .75 \left\{ 96 \text{ mW} - R \text{ (16 uW/ohm)} \right\} @ \alpha = 75\%$$

In one practical embodiment, the required operating voltage for the electronic circuits of the transmitter included in the two-wire telemetering system is the +5Vdc. As shown in Fig. 1, the current drawn from power supply 11 is represented as I_{PS}, the current going through microprocessor 14 supplied with power by regulator 17 is represented as I_{DC}, the current passing through signal output transistor 16 is represented as I_{CTL}, and the 4 to 20 mA current passing through resistor R_{FB} is represented as I_{OUT}.

We shall now assume that instead of a switch-type regulator, use is made in Fig. 1 of a linear regulator. With linear regulation applied to this system, the major consideration is then that I_{DC}, the current dissipated by the +5Vdc microprocessor 14 and the electronics associated therewith is always equal to or slightly less than I_{PS}, the power supply current. In addition, since $I_{PS} + I_{CTL} = I_{OUT}$ (the transmitter output current which is in the 4 to 20 mA range), the intensity of I_{DC}, the current going through the electronic circuits in the transmitter cannot be permitted to exceed 4mA.

Typical design values for the linear regulation scheme are as follows:

I_{OUT} (minimum) = 3.8 ma — Input Conditions

V+/- (minimum) = 12.5 volts

I_{DC} (maximum) - 3.8 ma @ +5vdc

Power available for control electronics = 19 MW

Maximum loop load resistance @ 24vdc and 20.8 ma

$$\frac{(24 - 12.5)}{20.8\ \text{ma}} = 553\ \text{ohms}$$

When, however, the system is in accordance with the invention and includes a switching-type regulator 17, as shown in Fig. 1, to supply constant power to the electronic circuitry of the transmitter, the major consideration is that minimal power be dissipated by the regulator so that the power supplied to the electronic circuitry is only slightly less than the power supplied by the power supply. As a consequence, the current I_{DC} consumed by the transmitter electronics can be greater than the power supply current I_{PS}.

Typical design values for the switching regulator scheme are as follows:

I_{OUT} (minimum) = 3.8 ma

Regulator Efficiency (minimum) = 75% — Input Conditions

Loop Resistance (maximum) = 550 ohms

V +/- (minimum) = 6.5 volts

Power available for electronic circuitry of transmitter:

a) I_{OUT} = 3.8 ma

$$I_{DC} = \frac{.75 \quad 24-[3.8\text{ma}\cdot(550\Omega + R_{FB})] \quad 3.8\ \text{ma}}{5\text{vDC}} = 12.27\ \text{ma}$$

R_{FB} = 100 ohms, V @ input of power supply = 21.53 volts

a) @ I_{OUT} = 20.8 ma

$$I_{DC} = \frac{.75\,\{24-[20.8ma\ (550\Omega + R_{FB})]\}\,20.8ma}{5vDC} = 32.70\ ma$$

R_{FB} = 100 ohms, V input of power supply = 10.48 volts

Thus a comparison of linear regulation with switching-type power regulation in accordance with the invention leads to the following conclusions:

I. The switching-type regulator in the two-wire telemetering system affords significantly more power for the electronic circuits of the transmitter with 550 ohms of load impedance powered by a 24Vdc power supply and operating over a current range of 3.8 to 20.8 mA.

The linear regulator produces 19 MW of power, whereas the switching-type regulator yields 61.35 MW, resulting in a 222% increase in available power.

II. The switching-type regulator is capable of driving a significantly higher load resistance when the two-wire telemetering system is powered by a 24 volt power supply. A linear regulator with a minimum V+/- of 12.5V equals a 552 ohm load. A switching-type regulator with a minimum V+1/- of 6.5 V equals an 841 ohm load. This represents a 50% increase in drive capability.

While there has been shown and described a preferred embodiment of a two-wire telemetering system including power regulated transmitting device in accordance with the invention, it will be appreciated that many changes and modifications may be made therein without, however, departing from the essential spirit thereof.

CLAIMS:

1. A two-wire telemetering system comprising:

(a) a DC powered transmitting device having power supply input terminals connected to an internal electronic circuit, said device being responsive to a variable of interest to yield a power supply direct-current output in accordance within said variable in a predetermined current range;

(b) a two-wire line, one end of which is connected to the output of said transmitting device to convey said power supply current;

(c) a receiving station remote from the transmitting device provided with a DC power supply and a load resistor in series therewith connected to the other end of line to receive said power supply current and to at the same time supply power to said transmitting device;

(d) a switching-type power regulator connecting the power supply input terminals of the transmitting device to said one end of the line, the regulator supplying current to the internal circuit of said device that is higher than the power supply current.

2. A telemetering system as set forth in claim 1, wherein said regulator is of the step-down type.

3. A telemetering system as set forth in claim 2, wherein said regulator includes a switching transistor which is turned on and off at a predetermined frequency to supply voltage from said supply to an inductor-capacitor filter.

4. A telemetering system as set forth in claim 1, wherein said variable is a process variable that is metered_by a sensor.

5. A telemetering system as set forth in claim 4 in which the sensor produces an analog signal that is applied to a microprocessor-controlled circuit in the transmitting device whose output yields said power supply current.

6. A telemetering system as set forth in claim 5, wherein said power supply current is applied to an output transistor coupled to said one end of the line.

7. A telemetering system as set forth in claim 6, wherein said sensor is a differential-pressure transducer.

8. A telemetering system as set forth in claim 1, wherein said regulator delivers constant power to said device under high voltage-low current as well as under low voltage-high current conditions.

9. A two-wire telemetering system substantially as hereinbefore described with reference to the accompanying drawings.

Amendments to the claims have been filed as follows

1. A two-wire telemetering system comprising:

(a) a DC powered transmitting device operating at a predetermined voltage and having power input terminals connected to an internal electronic circuit, said device being responsive to a variable of interest to yield at its output a direct-current signal in accordance with said variable in a predetermined current range;

(b) a two-wire line, one end of which is connected to the output of said transmitting device to convey said signal;

(c) a receiving station remote from the transmitting device provided with a DC power supply having a voltage at least twice as high as said predetermined voltage and a load resistor in series therewith connected to the other end of the line to receive said signal which is applied to a receiver and to at the same time supply power from said DC supply to said transmitting device; and

(d) a switching-type step-down power regulator interposed between the power input terminals of the transmitting device and said one end of the line, the output voltage of the power regulator always being lower than the voltage applied thereto from the power supply through the line, the power regulator yielding constant power under high voltage low current as well as under low voltage-high current conditions, thereby making more power available to the transmitting device and increasing its load drive capability.

2. A telemetering system as set forth in claim 1, wherein said regulator includes a switching transistor which is turned on and off at a

predetermined frequency to supply voltage from said supply to an inductor-capacitor filter.

3. A telemetering system as set forth in claim 1 or claim 2 wherein said variable is a process variable that is metered by a sensor.

4. A telemetering system as set forth in claim 3 in which the sensor produces an analog signal that is applied to a microprocessor-controlled circuit in the transmitting device whose output yields said direct current signal.

5. A telemetering system as set forth in claim 4, wherein said direct current signal is applied to an output transistor coupled to said one end of the line.

6. A telemetering system as set forth in any one of claims 3 to 5 wherein said sensor is a differential-pressure transducer.

7. A two-wire telemetering system substantial as hereinbefore described with reference to the accompanying drawings.

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